The RFID Radio Channel Applied to Vehicular Identification as a Tunnel Environment

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Abstract-**The Radio Frequency Identification System, a wireless communication system, recently is applied to vehicular identification; this motivates the analysis of the propagation environment for outdoor RFID systems. The RFID System applied to the vehicular identification consists of the reader, the tag and the radio channel, which is made up by the ground (asphalt), the free space and surrounded by walls (buses, vans, sport cars, etc., located at adjacent lanes). Therefore, radio link behavior, the radio channel can be analyzed when considering it involved in a tunnel environment and modeled as a waveguide in order to obtain the electromagnetic energy performance knowledge.**

Keywords- Reader; Tag; RFID

I. INTRODUCTION

The RFID communication system applied to the vehicular identification (AVI) is a radio mobile typical application, operating at 915MHz, and is based on the base station, the reader, and the mobile device is the tag, strapped on the motor vehicle windshield as shown in Fig. 1.

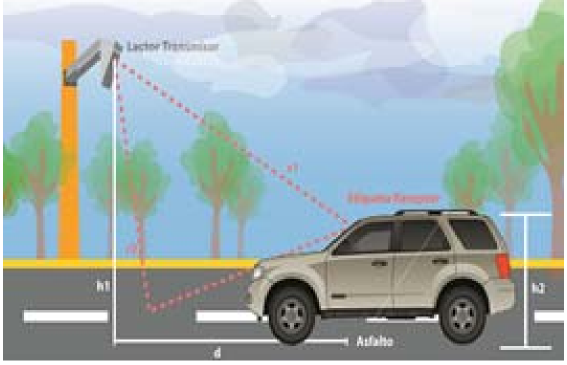

Fig. 1 RFID Technology applied to AVI

The RFID channel propagation operates under a complex electromagnetic environment, that is, the radio waves emitted by the reader, propagate, attenuating and joined to the reflected waves from the ground and adjacent vehicles. In this way, in order to obtain the electromagnetic energy performance knowledge, it is necessary take into account the structure and materials used at every location in the area, which is a deterministic channel model. A fully deterministic model requires a huge amount of structural data which are rarely available. Stochastic channel models predict average field strength and the variations around this average. A purely stochastic model does not take into account the details of the radio propagation environment. On the other hand, the ray tracing technique, the transmitter is modeled as a source of many rays in all directions around it. Each ray is traced as it bounces and penetrates different objects [1]. Nevertheless, the tracing calculation requires as input a detailed description of the environment, because every point of reflection of each ray from a surface has to be characterized in terms of the surface material and geometry.

So this motivates the analysis of the propagation environment for outdoor RFID systems applied to vehicular identification modeled as a tunnel environment. The vehicles located at adjacent lines of the vehicle under test, set up a wall, considering the radio channel as waveguide, the waveguide floor is made of uniform material, the waveguide ceiling is the free space and the walls are roughed, additionally, the variations of the electrical properties among the materials that constitute the walls, increases the effective roughness, as car windows, car wheels, etc.

In this way the suggested analysis in this work concentrates on the guiding of radio waves in tunnel environment and it is focused on the lateral walls made of lossy dielectric materials, the ground (asphalt) and the free space.

II. THE RFID PROPAGATION CHANNEL AS A TUNNEL ENVIRONMENT.

The tunnel is modeled as a hollow oversized waveguide where propagation is determined by a fundamental mode and an infinite number of higher order modes, from which the wall roughness causes coupling among the propagating modes, and previous analysis of the waveguide as a dielectric multi-mode [2], predicts the effects of production imperfections and the effects of mode coupling on the dispersion of the transmitted signals.

The objective in a dielectric slab waveguide is to contain energy within the structure and direct it toward a given direction. Over a cross section inside the guide far from the open ended [3], and the roughness waveguide, the field is formed with the incident and reflected waves of the dominant mode, but in the aperture and roughness, the discontinuity in this point, additional higher mode fields exist, most of the higher mode terms above the dominant mode will have cutoff frequencies greater than the operating frequency of the waveguide and thus will not propagate away from the vicinity of the discontinuity which causes them to arise. For the dielectric slab waveguide this is accomplished by having the wave bounce back and forth between the walls. When this is accomplished the refracted fields outside the dielectric form evanescent (decaying) waves and all the real energy is reflected and contained within the structure.

Fig. 2 shows the system as a hollow waveguide. The reader is installed in a fixed position, working as the transmitter and receiver simultaneously, and the tag, which is strapped on windshield of the motor vehicle, as a mobile receiver and starting the data back transmission to the reader. Making up the propagation media, we have the free space, the reflections from surface and the reflections from the various vehicles at side, forming the waveguide walls; these are made of homogeneous isotropic material with linear properties, the electric permittivity, whose complex permittivity has a large modulus [4] and the magnetic permeability. So inside the walls the depth of penetration will be small, such as the fields inside the walls near the surface will consist of a wave that is propagating, attenuating and joined to the reflected waves from the ground. Because of this the fields inside the walls the electric and magnetic are related in the following way:

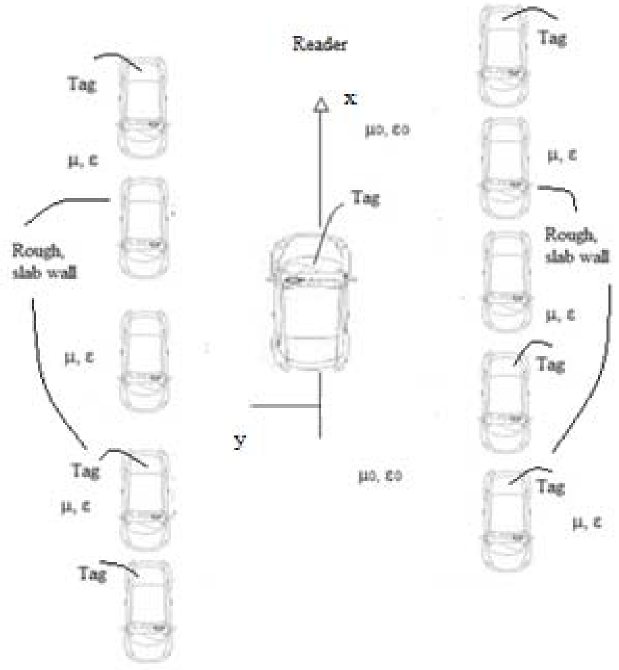

Fig. 2 The RFID channel as a hollow waveguide

$$\vec{E} = \eta \vec{n} \text{ X } \vec{H} \tag{1}$$

where:

$\vec{n}$, normal to the waveguide walls

η, intrinsic impedance:

$$\eta = \sqrt{\frac{\mu}{\varepsilon - j\sigma/\omega}}$$

At the interior of the waveguide the fields $\vec{E}$ and $\vec{H}$ are generated by the radiation of the reader´s antenna and the backscattered radiation from the tag antenna, from which, part of this radiation fall on the waveguide walls. So applying the tangential boundary condition, the tangential components of the electric and magnetic fields are continuous at both sides of a discontinuity, in this way:

$$\vec{n} \text{ X } \vec{E} = \eta \vec{n} \text{ X } (\vec{n} \text{ X } \vec{H}) \tag{2}$$

The ground reflection and the waveguide walls contribution can be replaced by the electric and magnetic surface currents, $\vec{J}w$ and $\vec{M}w$, respectively, and by the surface currents over the ground $\vec{J}G$ and $\vec{M}G$ as shown in Fig. 3.

where:

$$\vec{J}w = \hat{n}_W \text{ X } \vec{H} \quad \text{(3a)} \qquad \vec{M}w = -\eta \hat{n} \text{ X } \vec{J}w \quad \text{(3b)}$$

$$\vec{J}G = \hat{n}_G \text{ X } \vec{H} \quad \text{(4a)} \qquad \vec{M}G = -\eta \hat{n}_G \text{ X } \vec{J}G \quad \text{(4b)}$$

$\hat{n}_W$, normal to the waveguide walls

$\hat{n}_G$, normal to the ground

On the other hand, the ray techniques have been used to model tunnel propagation characteristics, but they present limitations, for example the ray divergence or the high number of rays that must be traced.

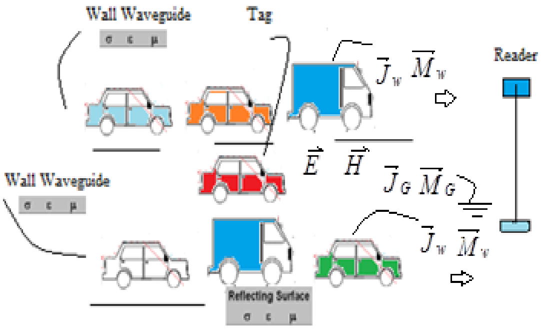

Fig. 3 Lateral vehicles make up the waveguide walls

The Iterative Physical Optics (IPO) is an alternative to ray techniques in order to predict the scattering from electrically large open ended cavities, it is an iterative solution of the Magnetic Field Integral equation (MFIE) based on the high frequency principles of Physical Optics. Moreover, the IPO method allows the inclusion of lossy walls and ground properties throughout the Impedance Boundary Condition (IBC) [4-6]. So, the surface wall current made up by the electric surface current and magnetic current expressed in the following way:

$$\vec{J}w_T = \hat{n}_t \text{ X } \vec{H}bs + \hat{n}_W \text{ X } \iint_{S_W} \vec{J}w \text{ X } \nabla\vec{G}0dS'_W$$
$$+ \frac{1}{jk\eta_0} \hat{n}_W \text{ X } \nabla \text{ X } \iint_{S_W} \vec{M}w \text{ X } \nabla\vec{G}0dS'_W$$

From (3b), and adding the backscattered energy from the tag, it is given by:

$$\vec{J}w_T = \hat{n}_t \text{ X } \vec{H}bs + \hat{n}_W \text{ X } \iint_{S_W} \vec{J}w \text{ X } \nabla\vec{G}0dS'_W + \frac{1}{jk\eta_0} \hat{n}_W \text{ X } \nabla \text{ X } \iint_{S_W} \eta(\vec{J}w \text{ x } \hat{n}_W) \text{ x } \nabla\vec{G}0dS'_W \tag{5}$$

where: $\vec{H}bs$, backscattered magnetic field from the tag antenna

In like manner, the ground current is given by:

$$\vec{J}G_T = \hat{n}_t \text{ x } \vec{H}bs + \hat{n}_G \text{ x } \iint_{S_G} \vec{J}G \text{ x } \nabla\vec{G}0dS'_G + \frac{1}{jk\eta_0} \hat{n}_G \text{ x } \nabla \text{ X } \iint_{S_W} \eta(\vec{J}G \text{ x } \hat{n}_G) \text{ x } \nabla\vec{G}0dS'_G \tag{6}$$

where:

k, wave number

η_0, intrinsic free space impedance

$\hat{n}_t$, normal to the tag antenna

And:

$$\nabla \vec{G}0\left(\vec{R}\right) = \hat{R}\left(jk + \frac{1}{R}\right)\frac{e^{-jkR}}{4\pi R}$$

This way once the wall and ground currents are known the electric field can be obtained by the following way:

$$\vec{E} = \vec{E}bs + \frac{\eta_0}{jk} \text{ x } \iint_{S_W} \vec{J} w_T \text{ x } \nabla \vec{G}0 dS'_W + \frac{\eta_0}{jk} \nabla \text{ x } \iint_{S_W} \vec{J} G_T \text{ x } \nabla \vec{G}0 dS'_G \qquad (7)$$

where:

$\vec{E}bs$, backscattered electric field from the tag antenna

The complexity of the integrals is clear, what is more, closed form solutions for fields depending in time and space, excited for distributed sources depending in time and space too, are difficult to obtain. However there are various formal solutions for this kind of problem, but the explicit evaluation requires a complicated integration process, depending again of the time and space distributed sources. Actually the team is working on it.

For practical purposes, the Expression (7) summed up the radiated electric fields.

III. MEASUREMENTS

To make the measurements some factors must be considered that include the reader's antenna position, the location and orientation of the tag on the vehicle's windshield, the inclination of the vehicle's windscreen, the radiation pattern of the reader's antenna and that of the tag's antenna. Other factors are the electrical and physical characteristics of the asphalt, the speed of the moving vehicles and the nearby traffic conditions. All scenarios are analyzed considering the RF signal emitted by the reader, the effect of antenna coupling polarization (reader-tag), the RF signal multi-rays and the dispersion of the generated signals for different vehicle heights.

The measurements were taken using a log-periodic antenna, a spectrum analyzer and a data acquisition program. Fig. 4 shows a measurement scene on the road.

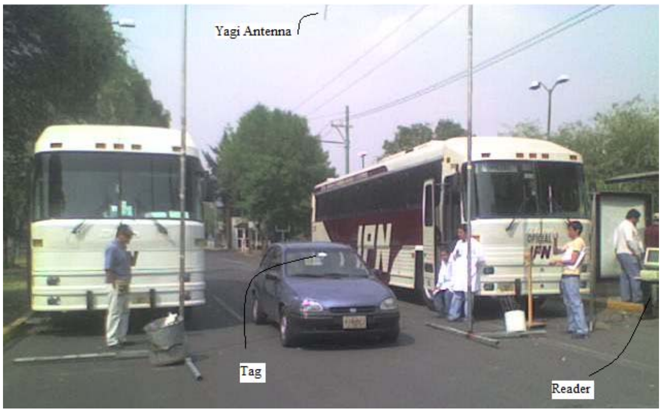

Fig. 4 Buses form a dielectric wall

Fig. 4 shows a car crossing the test area when the buses at each side making the dielectric wall. For a regular hallway, the width is approximately 9 meters; with regard to the adjacent distance to the vehicles is 3 meters, the antenna Yagi as receiver-transmitter reader antenna, the tag installed 1.2m above the ground, strapped on the motor vehicle under test and a 45° tilted reader antenna transmitted with 4w EIRP from a 5.4m tall bridge. RFID operation frequency 915MHz, the parameter as the complex permittivity given for ε_r, is the relative dielectric constant of the reflecting surface, considering a typical relative permittivity of $\varepsilon_r = 5$ for dry asphalt and $\varepsilon_r = 15$ for wet asphalt and a typical conductivity of $\sigma = 0.005$ S/m [7].

The results presume the presence of a direct propagation path. However, line of sight shadowing may occur when a tag to be read is in the nominal reader foot print and the tag is behind a tall vehicle that obstructs the direct path. In a practical scenario the tag to front vehicle distance is determined by the car hoot and the safety guard distance that tends to increase with vehicles' speed reducing the likelihood of a mobile being in a shadowing region, see Fig. 5.

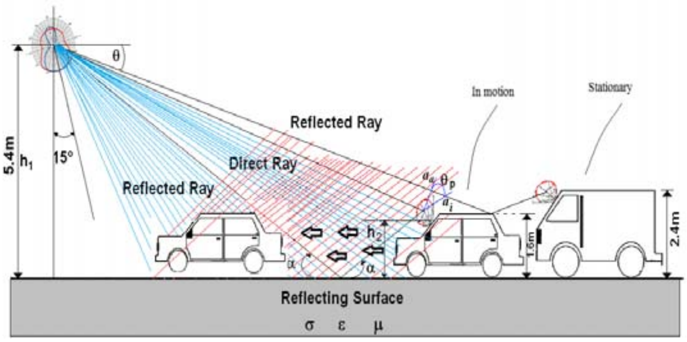

Fig. 5 RFID System applied to the vehicular identification under traffic jam environment

In traffic jam conditions the vehicles separation will be less and the speed will also be reduced increasing the number of readings as the mobile stays longer in the interrogator footprint.

The vehicle crosses the portal at different speeds, as shown in Fig. 6. The test results in road casts doubts on the tag detection performance, due of the number of successful readings is lower when the vehicle crosses the portal at high speed (> 120 Km/hr). This tag detection performance at high speed represents a weakness of the system applied to vehicular identification.

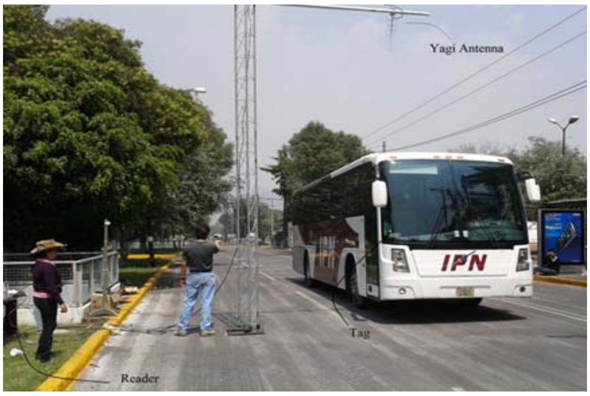

Fig. 6 Measurements in the road

Fig. 7a and 7b show the lateral and superior view of the measured power distribution respectively, when the Yagi antenna is vertically polarized. It is clear that the energy is concentrated in the middle of the covered area when the mobile crosses it.

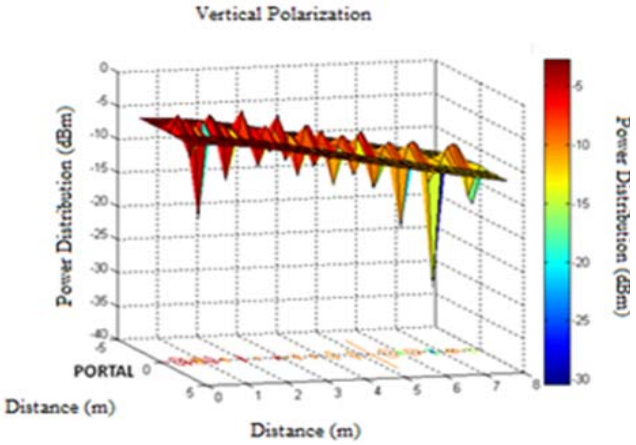

Fig. 7a Measured power distribution, lateral view, Yagi Antenna vertically polarized

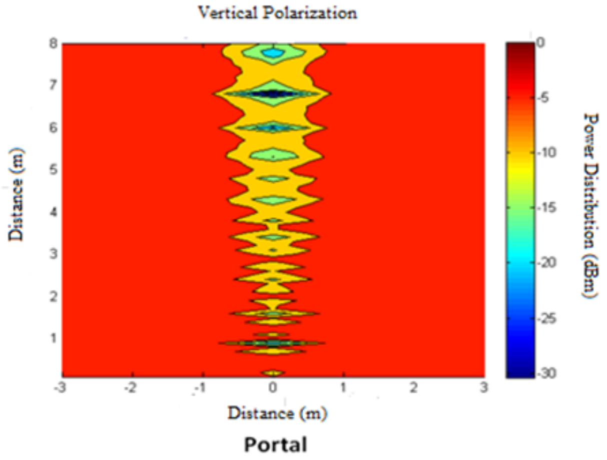

Fig. 7b Measured power distribution, superior view, Yagi Antenna vertically polarized

In the same way, Fig. 8a and fig. 8b show the measured power distribution when the Yagi antenna is horizontally polarized.

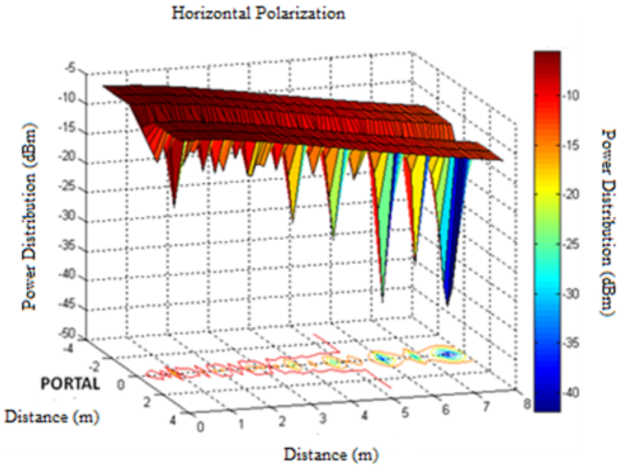

Fig. 8a Measured power distribution, lateral view, Yagi Antenna horizontally polarized

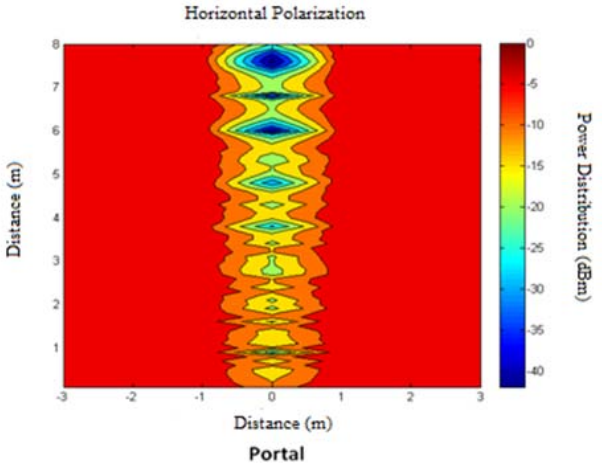

Fig. 8b Measured power distribution, superior view, Yagi Antenna horizontally polarized

The backscattered energy from the tag antenna, horizontally or vertically polarized is added to the energy radiated by the reader and to the reflected energy from the walls and ground. Because of the tag antenna strapped on the motor vehicle is horizontally polarized, and if the Yagi antenna polarization is horizontal too, the measurements, in this case, show a bigger concentration of the energy in the middle of the area.

IV. CONCLUSION

An approach to the radio link behavior is discussed in this work, supported by measurements taken in field, showing a proposal in relation to the electromagnetic energy performance of the RFID radio channel, when the system is applied to the vehicular identification, considering it as a tunnel environment, based on the wall and surface currents only, as a waveguide model. In contrast to ray tracing, only a very simple description of the environment is required, describing the wall average electrical parameters (dielectric constant and conductivity). Nevertheless, the tunnel environment technique does not take in account other factors as reader’s antenna position, the location and orientation of the tag antenna, etc. So, this technique in joint account with the ray technique is a useful tool to understand the electromagnetic energy performance in the RFID Radio Channel applied to vehicular identification.

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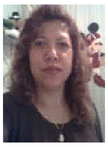

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